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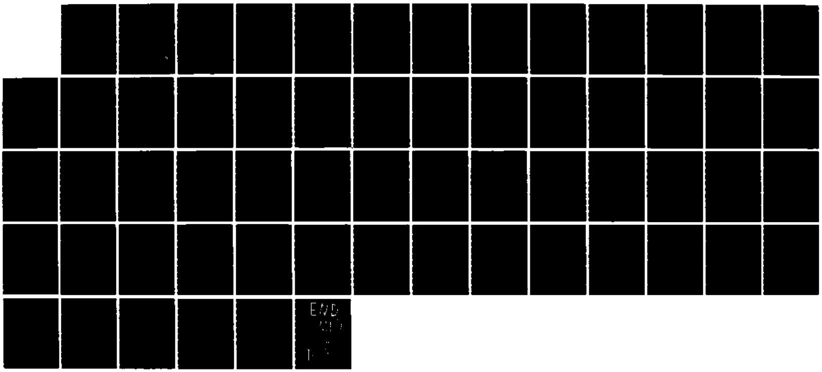

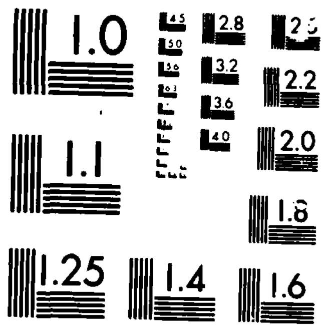

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFIT/CI/NR 86-27T	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Improving the Interpretability of an Aircraft Attitude Indicator.		5. TYPE OF REPORT & PERIOD COVERED THESIS/~~DISSERTATION~~
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Mark Anthony DiPadua		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS AFIT STUDENT AT: University of Massachusetts		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS AFIT/NR WPAFB OH 45433-6583		12. REPORT DATE 1986
		13. NUMBER OF PAGES 51
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASS
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

APPROVED FOR PUBLIC RELEASE: IAW AFR 190-1

Lynn Wolaver
LYNN E. WOLAVER 1 April 86
Dean for Research and Professional Development
AFIT/NR, WPAFB OH 45433-6583

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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IMPROVING THE INTERPRETABILITY
OF AN AIRCRAFT ATTITUDE INDICATOR

A Thesis Presented

by

Mark Anthony DiPadua

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE

February 1986

Industrial Engineering and Operations Research

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Approved as to style and content by:

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QUALITY INSPECTED

Richard J. Giglio, Department Head

ACKNOWLEDGEMENTS

I am indebted to Dr. Jefferson M. Koonce who more than helped to nurture the ideas behind this research and make them a reality. His guidance and teaching have been invaluable in the formatting of ideas, concepts, and hypotheses that have shaped this thesis. I am also indebted to Dr. Bruce G.Coury, who served on my thesis committee with Dr. Koonce. Dr. Coury provided me with keen statistical insight and has contributed a great deal in helping me format ideas and constructs. I finally would like to acknowledge my wife Anne for her support and love during this past year. She has made the past twelve months a great joy and success.

ABSTRACT

Two display types and four aircraft size ratios were investigated in this ~~experiment~~ to determine their effect on attitude display interpretability. The two display designs used were an outside-in (moving plane) and an inside-out (moving horizon) display. The four aircraft symbol lengths were measured relative to the size of the artificial horizon (33%, 50%, 67%, 100%). Twenty flight naive subjects were tested in two phases with both display types and all four size ratios. The first phase tested subjects' reaction to the sudden awareness of a change in attitude. The dependent variables measured, reaction time and error rate, indicated a preference for the outside-in display. The small size ratio was significantly better than the larger ones with reaction time as the dependent variable. A significant difference between sizes was not the case when the dependent variable error rate was measured. The second phase consisted of a dynamic flying task on an Apple PC computer. The dependent measures were the root mean square (RMS) error due to roll and the RMS error due to pitch. A significant difference in display types, favoring the outside-in type, was found with the RMS error due to roll as the dependent measure. No significant differences were found when the RMS error due to pitch was used as the dependent measure. Sizes did, however, approach significance in this case.

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CHAPTER I

INTRODUCTION

In 1984, numerous aircraft accidents occurred resulting in many fatalities and lost aircraft. The fact that many of these accidents can be attributed to human error (over 80%) along with the fact that pilots often misinterpret flight display indicators (Roscoe and Johnson, 1970), have inspired researchers to look further into this phenomena.

Fitts and Jones in 1947 collected and analyzed accounts of 420 errors made by pilots while operating aircraft controls. The analysis of the data collected from the study disclosed and affirmed that the human's capabilities and limitations must be considered when designing aircraft equipment. Later in 1947, Fitts and Jones collected accounts of 270 errors made by pilots while reading and interpreting instruments (Fitts and Jones 1947, Sinaiko, 1961).

The data error was obtained through interviews and written reports. The reported errors were classified into nine categories (Fitts and Jones 1947 in Roscoe and Johnson, 1970):

1. errors in interpreting multirevolution instrument indications,
2. reversal errors,
3. signal interpretation errors,
4. legibility errors,
5. substitution errors
6. use of an instrument that is inoperative
7. scale interpretation errors,

8. errors due to illusions

9. forgetting errors.

The artificial horizon, or attitude indicator, was identified as a significant contributor to two of the categories, reversal errors and errors due to illusions. The errors associated with the use of the attitude indicator were relatively small (about 9% of total). However, the consequences of these errors are often tragic.

Reversal errors constitute a control action in opposition to the correct response, and therefore aggravate rather than corrects an undesirable condition. According to Fitts and Jones, a typical statement made by a pilot was: "I glanced away from the instruments while making a steep bank. Upon glancing back at the artificial horizon, I was confused as to the direction of turn indicated. Upon beginning to roll out, I used exactly opposite aileron control from what I should and thereby increased the bank to such an extent that it was almost 90° and considerably dangerous." The errors due to illusions numbered 14 and were attributable to the attitude indicator. these errors result from misconceptions of self-sensations and the instrument indications (spatial disorientation).

The mistake of moving a control in the direction opposite to the appropriate one was felt by Fitts and Jones to be closely related psychologically to reversed interpretation of an instrument reading. These errors occur when the control movement required for a particular purpose is the reverse of what is most "natural" or "expected" or when the direction of control movement conflicts with habits which have been established in flying other aircraft (Fitts and Jones 1947 in Sinaiko

1961). Errors often occur when an operator responds to controls that conflict with each other over some dimension such as direction of movement. These conflicts require the pilot to change their mental set each time they change tasks.

Fitts and Jones suggested design changes that would prevent reversal errors. Controls should be designed so that the relationships between all control-aircraft-indictor movements are the "natural" or "expected" ones and no mental process is required between comprehension of a display and response (Fitts and Jones 1947 in Sinaiko 1961).

More than three decades have passed since Fitts and Jones focused attention on the shortcomings of aircraft attitude indicators. The experimental evidence generated by researchers on attitude indicators has failed to conclusively soive the fundamental problem of how to display aircraft attitude and eliminate control reversals.

The research undertaken in this thesis does not merely focus on the merits of either display type but probes actual attitude display designs for possible insight into the control reversal phenomena. It is felt that the ratio of the aircraft symbol to the artificial horizon symbol is a factor that will affect the interpretability of an attitude indicator.

CHAPTER II

AIRCRAFT ATTITUDE DISPLAY

The attitude indicator in an aircraft conveys information concerning the aircraft's pitch (whether the nose of the aircraft is level, climbing, or descending) and the aircrafts' roll (whether the plane is level, rolled left, or rolled to the right). On September 24, 1929, James Doolittle proved conclusively that it was possible to take off and land an airplane by instruments alone (first actual use of an aircraft attitude indicator). Doolittle took off with his airplane cockpit completely covered, flew a distance of 20 miles, and landed at approximately the same spot he took off from (Roscoe and Johnson, 1970). Since Doolittle's flight, the frame of reference for display presentation of an aircraft's attitude has been a subject of controversy. The attitude indictor used by Doolittle was the Sperry Horizon which was the prototype for the conventional artificial horizon presentation used today.

John R. Poppen (1936), a Naval flight surgeon, presented a rationale for the motion relationship of the attitude indictor used by Doolittle. Poppen stated that the correct form of presentation was an exact analog of what would be viewed through the windscreen in contact flight. Poppen considered the display to be a porthole through which the pilot views a symbolic analog of the real horizon. Poppens' reasoning has prevailed through the years and is the basic rationale of the inside-out attitude display, predominately used today. Regardless,

the problem of misinterpretation and control reversals associated with this display remain.

The pilot's frame of reference is extremely important with respect to the presentation of aircraft attitude. In whatever capacity attitude information is displayed, it is necessary for the pilot to think that his aircraft, relative to the outside world, is moving. If he thinks that the outside world is moving, he is disoriented and subject to potentially fatal maneuvers.

Outside-In, Inside-Out

In the display of aircraft attitude, either of two basic coordinate systems may be employed. Earth coordinates or aircraft coordinates. Earth coordinates refers to three orthogonal axes fixed in position relative to terrestrial space (as opposed to inertial or celestial space). One axis is vertical and eminates from the center of the earth; the second is orthogonal to the first and is oriented relative to the north pole; the third is orthogonal to the first and second (Roscoe and Johnson, 1970). Roscoe et al stated aircraft coordinates refer to the longitudinal, lateral, and vertical (x, y, and z) axes of the aircraft. There are a variety of terms commonly used in referring to aircraft displays as indicated below (Roscoe and Johnson, 1970):

Earth Coordinate Displays	Aircraft Coordinate Displays
outside-in	inside-out
moving airplane	moving horizon
aircraft referenced or stabilized	earth referenced or stabilized
fly-from	fly-to

In the outside-in display, the earth coordinates are used as the reference system (moving aircraft with a static horizon). This display of altitude is as if one is looking at an airplane in the sky from the earth. The inside-out display uses the aircraft coordinates as the reference system (moving horizon with a static aircraft symbol). This display of attitude is as if one is inside the aircraft looking out at the moving horizon. With respect to the presentation of aircraft attitude, the issue is illustrated graphically in Figure 1. Regardless of the manner attitude information is displayed, it is vital that the pilot realizes his aircraft is moving. If the pilot thinks the outside world is moving, he/she is disoriented and subject to vertigo.

Moving Aircraft Outside-In

Moving Horizon Inside-Out

FIGURE 1: Types of Aircraft Attitude Display

Principles of Display

Roscoe (1968) stated six rules or principles that bear upon the design of flight and navigation display systems. Four of these six

rules play a considerable role in attitude display design. These four rules are indicated below:

1. The principle of display integration: The notion of display integration requires that related information be presented in a common display system which allows the relationships to be perceived directly. This principle does not apply to the haphazard combining of unrelated information in a common display
2. The principle of pictorial realism: This principle related to the presentation of graphic relationships in such a manner that the encoded symbols can be readily identified with what they represent; in effect, the symbols are an analog of that which they represent.
3. The principle of the moving part: This principle dictates that the direction of movement of an indicator on a display should be compatible with the direction of movement of an operator's internal representation of the variable whose change is indicated.
4. The principle of frequency separation: This principle relates to the relative speed of movement of display indications; when "high-frequency" (quick rapid changes) information is displayed, the moving element must respond in the expected direction (i.e., compatability of movement is especially critical); but when low-frequency information is displayed, the direction of movement is not as crucial.

The first principle would suggest that the attitude indicator as designed is appropriate. Highly related pieces of information such as

pitch and roll should be presented in a common display. This principle is adhered to by both the outside-in and inside-out displays. The principle of pictorial realism is also a strong design-guideline and is generally followed in aircraft attitude displays. The aircraft symbol in the display should be readily identified as the element representing the aircraft and should not be confused with the artificial horizon symbol. This principle is again adhered to by both the outside-in and inside-out displays. The principle of the moving part is a critical factor in the design of displays. In the outside-in display, this principle is in conformity as the aircraft symbol is the element that is moving. However, with the inside-out display we see a clear violation of the principle of the moving part (the artificial horizon is the element that moves in this display). The principle of frequency separation tends to suggest an alternate design for an aircraft attitude indicator. When quick, high frequency changes are incurred, the display will conform to the outside-in display design (moving aircraft). This will tend to reduce or minimize the number of control reversals generally associated with an inside-out display. When slow, low-frequency changes are incurred, the display will conform to the inside-out display design (moving horizon).

The principles outlined above tend to exploit the strengths and weaknesses of the two display designs (i.e., outside-in and inside-out). To recapitulate concisely, the outside-in display adheres to the principle of the moving part. This display, however, intrinsically provides a frame of reference (a view from outside the aircraft) that is inconsistent with the pilot's actual frame of

reference (inside the aircraft). Therefore, the outside-in display violated compatibility of orientation (Wickens, 1983). The inside-out display does not violate the compatibility of orientation but does violate the principle of the moving part. This violation is considered the main cause for the excessive number of control reversals on the inside-out display.

Figure and Ground

The psychological phenomenon of figure and ground may offer an explanation to the problem of pilot errors on inside-out attitude displays. Roscoe and Johnson (1972) stated that although figure-ground definitions emphasize static aspects of the visual field, dynamic aspects dominate the flight situation. Psychologically, the part of the field of view that appears to be stationary is customarily called the background, or simply the ground, and the object that is moving is called the figure. When the entire visual field moves in relation to the observers eye, as occurs with head movement, the observer usually perceives that he himself is moving and that the background is stationary (Fitts and Jones, 1947). The interesting question becomes, "do the figure and ground relationships between the aircraft and the outside world change when the pilot shifts his attention from the outside world to his attitude indicator on the panel inside the cockpit?" (Roscoe and Johnson, 1972).

Woodworth (1938) claimed Rubin (1921) was the first to recognize the psychological importance of the figure and ground distinction and

classified the phenomenal differences between figure and ground. Woodworth summarized Rubin's conclusions as:

1. The figure has form, the ground is generally formless, or if the ground has form, it is due to some other figuration on it and not the contour separating the figure and ground.
2. The ground appears to run into infinity, continuously around the figure.
3. The figure tends to appear in front, while the ground appears behind.
4. The figure is more impressive, better remembered, and more likely to suggest meaning.

The concept of figure and ground was used by Grether in 1947 to postulate a reason for reversals when interpreting flight displays:

> The actual horizon is normally accepted by the pilot as a fixed or stable frame of reference. It becomes a ground (or background) against which his and other aircraft are moving figures. When the horizon disappears, as in instrument flying, the pilot apparently shifts to the cockpit of his own aircraft as the stable reference or ground against which all moving pointers, including the gyro horizon bar, are reacted to as figures. The small, narrow, and fallible moving bar (artificial horizon), apparently cannot substitute for the distant, massive, and infallible true horizon as a stable frame of reference for the pilot. By reacting to the gyro horizon bar as figure instead of ground, he is led to an exactly reversed interpretation.

A shift in the figure-ground relationship would result in a change in the pilots frame of reference. This change occurs when a pilot views a small, abstract instrument representation of the outside world, as opposed to the outside world itself. In this case, the aircrafts'

instrument panel becomes the background against which the display elements move.

Roscoe (1980) gives an explanation of the psychological phenomena of figure and ground as it applies to the interpretation of an inside-out aircraft attitude display. Looking out the cockpit of an aircraft when the horizon is tilted, it is easy to see that the aircrafts' wings are banked and to make the appropriate response to level the wings. However, when looking at the small attitude indicator while seated in the cockpit the observer notes that the line on the attitude indictor has rotated clockwise and moves the control to stop this roll and level the wings. A counter clockwise input, control reversal, is often the result because the observer acts to stop the moving symbol and does not respond to it as representative of the real world horizon (fixed). The observer fails to realize that the aircraft, the instrument panel, and the instrument bezel which is stable relative to himself is really that which has banked. Roscoe notes that pilots do not have much difficulty with a moving horizon display under most circumstances, but when making a rapid response to sudden awareness of an indicator of a roll, the tendency for a control reversal is much greater. According to Roscoe, "The problem seems to be associated almost exclusively with fast responses to slow changes in display indications."

CHAPTER III

IMPROVING THE ATTITUDE INDICATOR: WHAT SHOULD MOVE?

A great deal of research has been conducted on the attitude indicator generally focussing on the merits of either the inside-out or Outside-in type of display. The controversy over the means of displaying the attitude of an aircraft has been firmly established in the research. Research has demonstrated that experienced pilots perform better than novices on the inside-out (moving horizon, fixed plane), display, and that novices generally perform better on the outside-in (moving plane fixed horizon), display than with the inside-out display. One explanation offered for this is that experienced pilots have learned to respond to a moving horizon and to moving horizon-type attitude displays, while novices view the horizon as fixed with moving airplanes and thus tend to "fly the horizon" when it moves resulting in control reversals. Regardless, experienced pilots generally committed an excessive number of control reversals with the inside-out display.

With respect to the presentation of an aircrafts' attitude, the central question, whether the aircraft symbol or horizon symbol should move, remains unclear after many years of controversy. This is partly due to a lack of validity of results from ground-based simulator experiments in which physical acceleration cues are believed to be important and the inconclusive results from flight experiments (Roscoe and Johnson, 1971).

Browne (1945) was the first to experimentally compare the presentation of aircraft attitude indicators utilizing a standard instrument trainer to do so. The display Browne used included conventional British instrument in which the aircraft symbol was stationary in the center of the display and the artificial horizon moved in the customary fashion. The other display was experimental in design such that the artificial horizon bar segments were fixed on each side of the display and the aircraft symbol moved in relation to the bar segments indicating bank and pitch angles. Browne ran cadets in flight training, who had not yet been exposed to actual aircraft attitude displays as subjects and concluded after two experiments that, "It does not matter which of the two (airplane or horizon) is moving and which is fixed."

Browne also tested 20 experienced pilots who preferred the experimental display (outside-in) and showed small but non-significant performance differences in its favor. The pilots had an average of 300 hours of flight time. The sequence of use of the displays were the same for every other subject thus counterbalancing for any variation due to sequence of use.

In 1947, Loucks compared four types of experimental attitude indicators with the conventional instrument, using subjects with no previous experience (Roscoe and Johnson, 1970). The four experimental displays differed from the conventional display in the following manners:

1. Bank scale marks were removed.
2. Bank scale rotated with the horizon line.

3. The bank scale was positioned below the horizon line.
4. Rotation of horizon line was reversed from that of the conventional display.

Louke concluded from his studies that the reversed rotation display was substantially superior to the conventional attitude indicator and was preferred by the student pilots. This was the case in spite of the fact that when the aircraft assumes a right roll attitude, the indicator registers this maneuver by showing the aircraft symbol with its left wing dipped below the horizon bar.

Studies conducted at Hughes Aircraft Company between 1953 and 1960 (as cited by Roscoe and Johnson, 1970), investigated pilot steering performance in radar-directed interceptor attacks. The results from these studies did not reflect the pronounced superiority of the outside-in (moving airplane) display observed in previous simulator studies.

In 1955, Casperson of Dunlap and Associates, Inc., conducted a study to determine whether ex-pilots could adapt to the moving-aircraft type of display more quickly than they could re-adapt to the one they had used, the moving horizon. Eight pilots participated as subjects in this experiment with an average interval of 5.8 years since their last flight. The tests were carried out in a fixed-base C-11B jet simulator with control responses approximating those of an F-80 aircraft. The subjects flew a variety of maneuvers and in the last phase were required to recover from unusual flight attitudes. "Control reversals while using the moving-horizon display were 3.6 times the number with the moving-aircraft display. The moving-aircraft display also proved

to be significantly superior in the amount of time the pilots needed for recovery from the unusual attitudes" (Dunlap and Associates, Inc., 1955, in Roscoe and Johnson, 1970).

A study conducted by Bell Helicopter Company (Matheny, Dougherty, and Willis, 1963 in Roscoe and Johnson, 1970) dealt with the question of attitude display motion relationships in different experimental environments. They compared performance on moving horizon and moving aircraft display presentations under both fixed-base and moving-base simulator conditions. The simulator was capable of moving in six degrees of freedom, three rotational and three translational.

The three displays used in the study presented a geometrical projection of a ground plane represented by grid squares with a sharp horizon line and a clear sky. In the first display, an aircraft symbol moved against a fixed grid plane. The second display had a moving grid plane with the aircraft symbol fixed in the center. The third display was the same as the second, except no aircraft symbol was presented. The subjects were required to make judgements of the direction of pitch, roll, or both as given by the visual display.

The result obtained from the static simulator condition indicated the percent judgements in error for the moving aircraft display (outside-in) was less than for the moving horizon display (inside-out). Results from the moving-base simulator conditions did not indicate a significant difference between the two displays.

The merits of the outside-in (moving-aircraft) versus the inside-out (moving-horizon) had certainly been firmly established in the research by 1960. Other methods aimed at improving the

interpretability of the attitude indicator, such as the use of color, were addressed by Robert Woodruff. Woodruff (1979) conducted an experiment involving 32 Air Force undergraduate pilots who learned approach and landing procedures in a T-4G simulator using either black and white or colored imagery in the displays. Significant differences were not found in this experiment. Power analysis showed that the experiment would have detected a significant difference, if one existed, with a probability of more than .75. A more basic design approach is therefore needed to enhance the attitude indicators' interpretability.

CHAPTER IV

ARTIFICIAL HORIZON AND AIRCRAFT SYMBOL RATIO

Enhancing Interpretability

The literature has indicated in certain studies the outside-in display allows the best performance and in other studies the inside-out display is best. The research for the most part has demonstrated that novices perform significantly better (having fewer control reversals) using a display which represents the horizon as a fixed element and the symbol representing the aircraft as the moving element outside-in). Although experienced pilots performed better than novices when using the inside-out displays, the number of control reversals were often considered to be excessive.

The reason for the differences in performance using these displays seem to have been overlooked, and the mere results of the trade-off studies comparing the two methods of display were sufficient for claiming the virtues of the outside-in over the inside-out method of displaying aircraft attitude. In the current literature, no studies have been found that focus on the relative size of the aircraft symbols wing to the length of the horizon as a factor affecting the interpretability of an attitude indicator. In an article by Shimon Ullman (1980) the correspondence between line segments in apparent motion is shown to be affected by the similarity between them. An increase in the length ratio between lines in a competing motion configuration was shown to decrease the probability of perceived

apparent motion between them. Therefore, in a configuration such as in Motion A (Figure 2) one would not be able to easily detect changes in motion, whereas in Motion B (Figure 2) changes would be detected more easily.

FIGURE 2: Similarity Between Symbols

The intent in this research is to demonstrate that proper interpretation of an attitude indicator is affected by the length ratio of the aircraft symbol to the horizon symbol. The four ratios, namely 33%, 50%, 67%, and 100%, have been selected for comparison based on data made available in a preliminary study. The specific hypothesis of this research would be as follows: As the relation of the aircraft symbol to the artificial horizon symbol becomes smaller, the probability of a control reversal should decrease. With a smaller aircraft symbol, it would be easier to discriminate the artificial aircraft from the horizon and thus interpret the display more accurately than when the aircraft symbol is nearly as large as the artificial horizon symbol. It would also be easier to perceive motion with a smaller aircraft symbol. In addition, it is hypothesized that reaction times will be faster when the ratio of aircraft symbol to the

horizon symbol is smaller and will progressively increase as the ratio increases. Finally, since flight naive subjects will be used, it is hypothesized that the outside-in display will outperform the inside-out display.

Methodology

Subjects

Twenty flight naive subjects were used to study the effects of various displays in two phases. (The subjeccs were all graduate or undergraduate engineering students, of which 12 were male and 8 female.) Phase-1 was a static test and enabled the researcher to test the displays for susceptability to control reversals. As Roscoe indicted, the control reversal phenomena seems to be ideally linked to a sudden awareness of a change in attitude. This phase was designed to provide subjects with sudden changes in attitude. The second phase consisted of a dynamic tracking task in which subjects were required to hold an aircraft symbol level, and on the horizon. This phase of the experiment provided subjects with instantaneous feedback and provided the researcher with an apparatus to measure realistic performance of the displays. In an effort to avoid problems of confounding, the sequencing of phases were counterbalanced across subjects.

Task

In Phase-1, 72 slides were viewed by each subject: 36 of the outside-in variety and 36 inside-out. Each slide depicted a plane in various degrees of roll and pitch with respect to the horizon. The horizon and the plane symbol were white on a dark gray background (there was no sky-earth differentiation). The planes depicted on the slides were of various lengths with respect to the horizon, specifically 33%, 50%, 67%, and 100% of the horizon. These four ratios were found to provide significant differences in responses among subjects run in a preliminary study. The 20 subjects were asked to perform the proper control responses to level the wings. The dependent variables measured were reaction time and appropriateness of control response.

Reaction time was the time required for a subject to perceive a particular maneuver on a slide, make the appropriate decision, and provide a response to the control stick. An appropriate response was one that was undertaken in a manner that would correctly align the aircraft symbol with the horizon. The independent variables in this phase were display type (two levels: outside-in, inside-out) and size ratio (four levels: 33%, 50%, 67%, 100%). Dependent variables measured were reaction time and error rate.

The second phase of the experiment consisted of a dynamic tracking task and had as its dependent measure the root mean square error. The independent variables were again the two display types and the four levels of sizes. The root mean square error was calculated as the

square root of the average squared deviations. Subjects in this phase were required to maintain a level aircraft as depicted on a computer screen while a disturbing-function randomly moved the plane.

Procedure

The subjects were given a standard introduction to the experiment and underwent practice trials for each phase. In phase 1, the static portion of the experiment, each subject was seated in a sound-proof room and viewed slides that were projected through a window in the booth (each slide depicted an aircraft and an artificial horizon in a certain roll and pitch). Subjects utilized a control stick attached to their chair to convey their reactions to a strip chart recorded.

Since the displays were not affected by a subjects control action, feedback was manually provided. This feedback consisted of making a subject aware of any inappropriate responses. If a correct response was recorded for a display, no feedback was rendered. The two pens on the strip chart recorder were used to measure roll, left or right, and pitch, climb, or dive. The left pen being sensitive to roll quite obviously moved to the left when a subject moved the control stick to the left and moved to the right for a right control stick input. The right pen being sensitive to pitch moved to the left for a dive (pushing forward on the control stick) and right for a climb (pulling back on the control stick).

A slide projector was used to display the various maneuvers through the window. Reaction time was determined from the moment a slide was

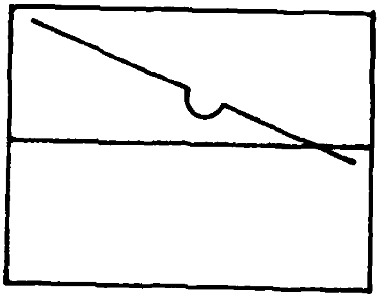
shown, to the instant the pens on the strip-chart recorder moved in accordance with a subjects response. The order of display type presentation (outside-in or inside-out) was counterbalanced for successive subjects. (Half of the subject viewed the outside-in slides first and the other half viewed the inside-out slides first.)

The maneuvers required of the subject in phase 1 were randomly arranged and consisted of the following required responses:

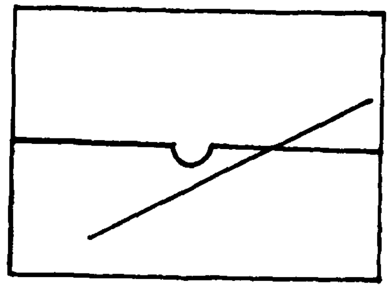
TABLE 1: Required Maneuvers

Dive Left 15°
Climb Left 45°
Dive Left 45°
Dive ---- 0°
---- Left 45°
---- Right 15°
Dive Right 15°
Dive Right 45°
Climb Right 45°

These nine maneuvers each with four size ratios comprised the 36 slides at each display type. These maneuvers were used in a preliminary study and were found to be appropriate. The 36 outside-in slides were randomly arranged in a slide carousel. The 36 inside-out slides were also randomly arranged in a separate slide carousel. Once randomized, the ordering of the slides for either display type were consistent for all subjects. The nine maneuvers over the two display types used, are depicted in Figure 3.

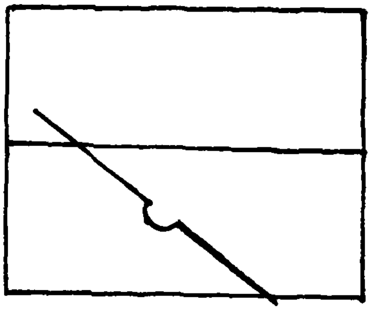


Outside-In



Inside-Out

Dive Left 15°



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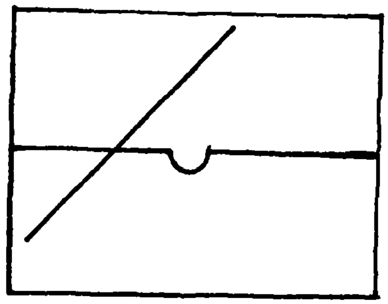
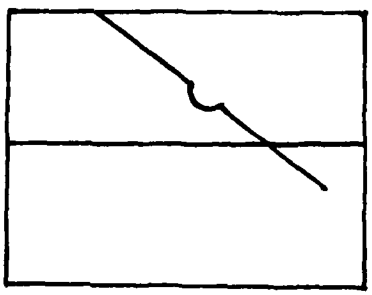
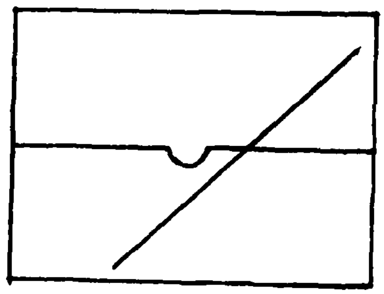


Inside-Out

Climb Left 45°



Outside-In



Inside-Out

Dive Left 45°

FIGURE 3: Actual Depiction of Required Maneuvers

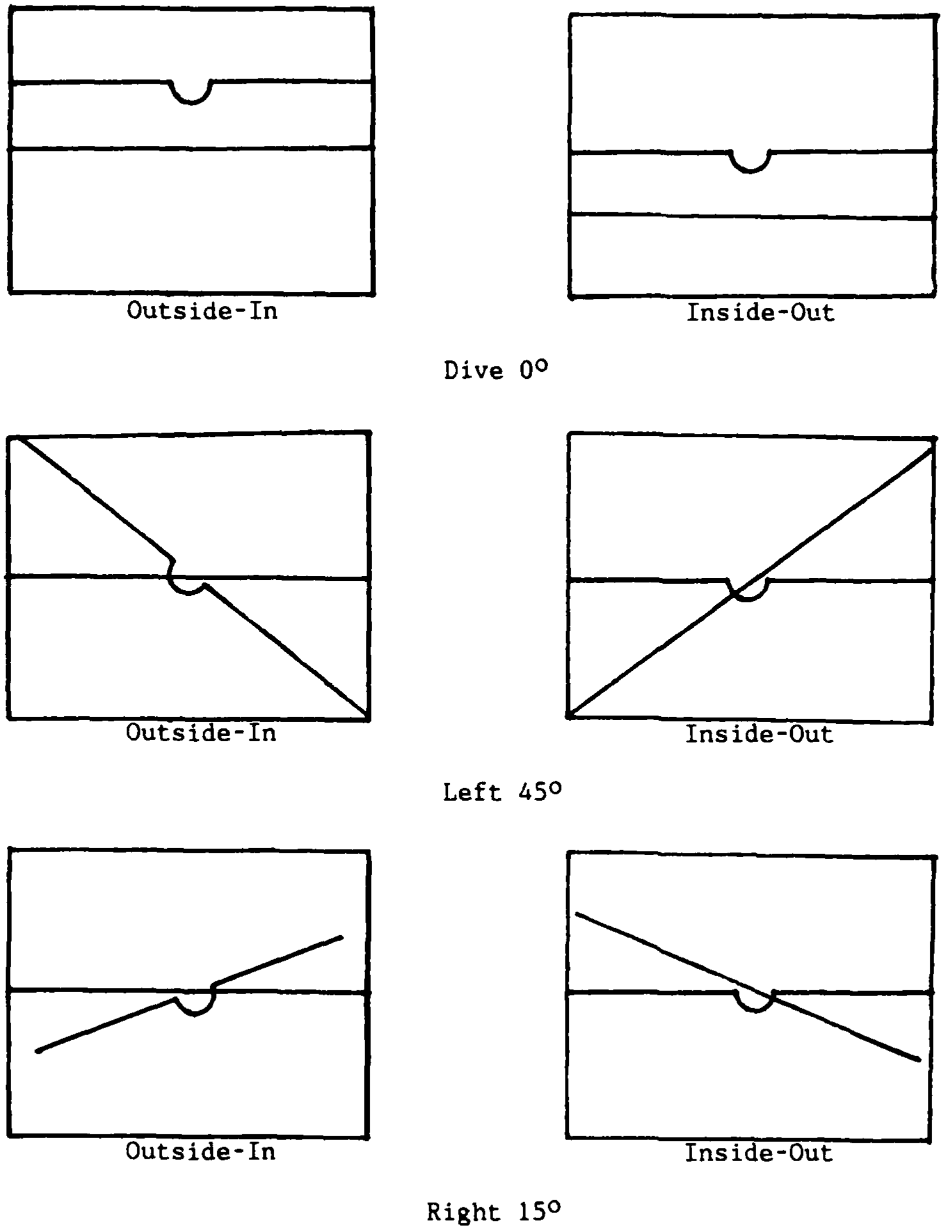


FIGURE 3: Actual Depiction of Required Maneuvers (continued)

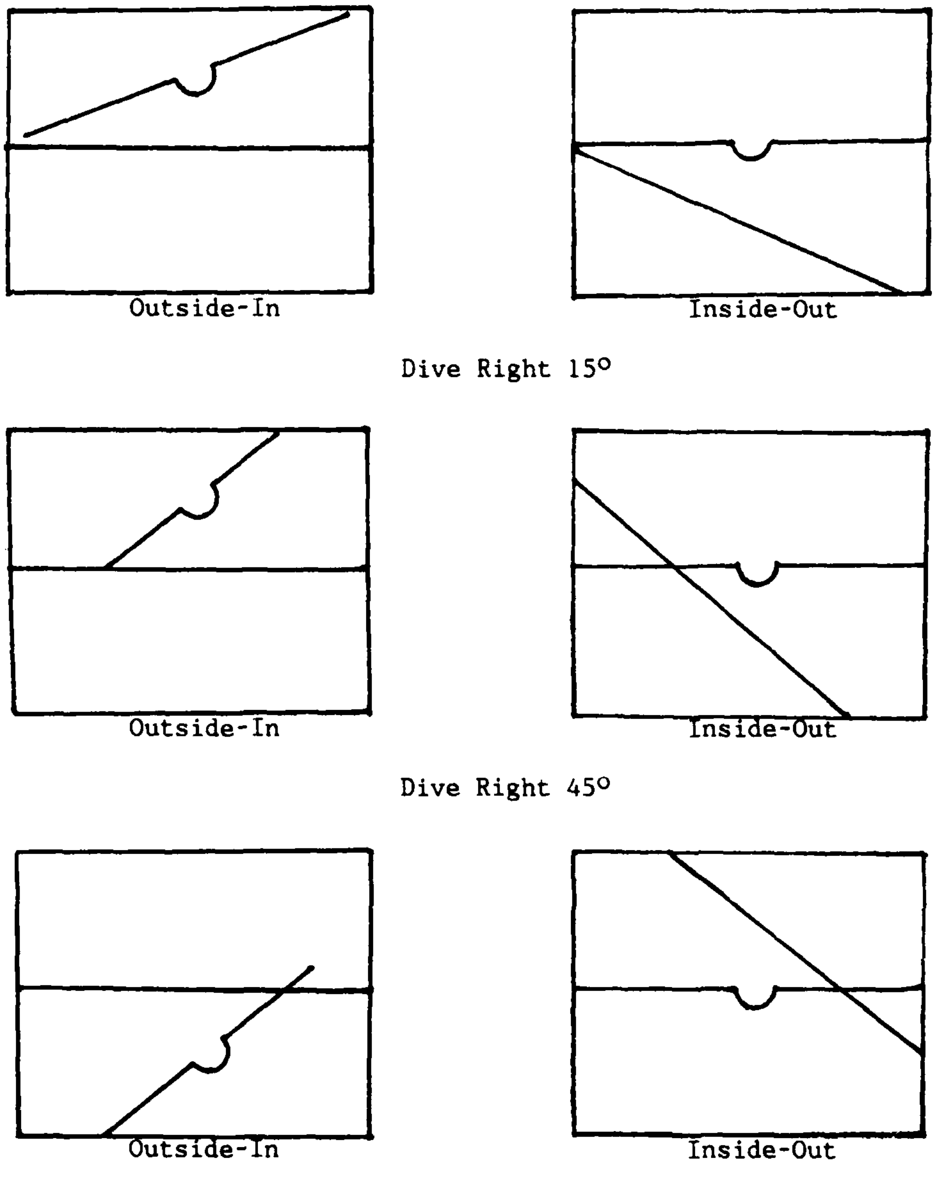


FIGURE 3: Actual Depiction of Required Maneuvers (continued)

The experimental layout for the first phase will be as indicated in Figure 4. In this layout there are two levels of display (D), four levels of sizes (S), nine different maneuvers (M), and twenty subjects (n1-n20). Displays and sizes are crossed and the nine maneuvers are nested within each display by size combination. (The dependent measures at each display by size cell were arrived at by averaging over the nine maneuvers at that cell.) All twenty subjects viewed all levels of display, sizes, and maneuvers.

In phase 2, the dynamic portion of the experiment, each subject worked with an Apple 2C computer. All twenty subjects responded to the two display types and the four size ratios depicted on the computer screen. The software used depicted an aircraft symbol and a horizon with the aircraft randomly moving up and down on the vertical centerline and randomly moving in rotation. The subjects interacted with the computer via a joystick and made the appropriate responses to keep the aircraft level and on the horizon. The computer randomly selected the size ratio sequence. In an additional effort to avoid confounding, every other subject received the outside-in display first while the other subjects received testing on the inside-out display first. The computer recorded the root mean square (RMS) error for each trial and sampled RMS error every one second. The eight trials (two display types by four ratios) were one minute each. This phase allowed the experimenter to compare the displays in a realistic environment. In addition to the counterbalancing of display type within each phase, the phases themselves were counter balanced. The sequence of phases changed with each successive subject.

	D1 (Outside-In Display)				(D2 (Inside-Out Display)			
	S1 (33%) M1-M9	S2 (50%) M1-M9	S3 (67%) M1-M9	S4 (100%) M1-M9	S1 (33%) M1-M9	S2 (50%) M1-M9	S3 (67%) M1-M9	S4 (100%) M1-M9
n1								
n2								
n3								
n4								
n5								
n6								
n7								
n8								
n9								
n10								
n11								
n12								
n13								
n15								
n16								
n17								
n18								
n19								
n20								

(Model: $Y_{ijk} = \mu + \alpha_j + \beta_k + (\alpha\beta)_{jk} + \epsilon_{ijk}$)

FIGURE 4: Experimental Layout and Model

The analysis of variance table for the two-factor repeated measurement design is indicated in Table 2. Display type (D) and size ratio (S) are both fixed-effect variables.

TABLE 2: ANOVA for Two-Factor Repeated Measurement Design

Source of Variance	Degrees of Freedom	Expected Mean Square
Total	159	
D (displays)	1	$\sigma_e^2 + 4\sigma^2_{DN} + 80\theta^2_D$
S (sizes)	3	$\sigma_e^2 + 2\sigma^2_{SN} + 40\theta^2_S$
N (subjects)	19	$\sigma_e^2 + 8\sigma^2_N$
DS	3	$\sigma_e^2 + \sigma^2_{DSN} + 20\theta^2_{DS}$
DN	19	$\sigma_e^2 + 4\sigma^2_{DN}$
SN	57	$\sigma_e^2 + 2\sigma^2_{SN}$
DSN	57	$\sigma_e^2 + \sigma^2_{DSN}$

As indicated by Table 2, displays are tested against the DN term, sizes are tested against the SN term, and the interaction display by sizes is tested against the DSN term. The expected mean squares have been derived assuming a non-additive model. (The variance due to interactions in the population was evident in a preliminary study, therefore lending credibility to the choice of a non-additive model.) The BMDP statistical software package was used to analyze the data.

Results

The data collected in the experiment was analyzed and evaluated using analysis of variance and certain post-hoc tests. The reaction time data indicated a significant preference for the outside-in display ($p<.05$), and a strong significant preference for the smaller (33%) ratio ($p=.01$). The error rate data also indicated a significant preference for the outside-in display as revealed by a chi-square test. The different size ratios did not, however, provide any significant results in this case.

In the dynamic phase of the experiment, RMS error was collected. The RMS error component, due to aircraft roll, indicated a significant preference for the outside-in display ($p=.02$), *but failed to indicate a* significant preference for the smaller size ratio. The RMS error component, due to aircraft pitch, indicated a non-significant preference for the outside-in display ($p=.24$). The aircraft size ratio did, however, approach significance in this case ($p=.09$). The total normalized RMS error did indicate a significant preference for the outside-in display ($p=.05$), but failed to indicate a significant preference for the smaller size ratio.

CHAPTER V

SUMMARY AND CONCLUSIONS

The analysis of the data typified the first hypothesis of the researcher, namely that the outside-in display would be superior to the inside-out display. This outside-in display was consistently below the inside-out display when graphed as a function of reaction time, error rate, roll RMS data, pitch RMS data, and total RMS data (Figures 5, 6, 7, 8, and 9 respectively). The difference in display types was significant in Figures 5, 6, and 7.

The results depicted graphically in Figure 5 also indicate a significant size ratio main effect. The second hypothesis predicted the reaction times would be longer for the larger ratios than for the smaller ratios. The results in this case indicated an average reaction time for the four ratios as follows:

33% ratio, average reaction time = 1.415 sec. (standard deviation .53)
50% ratio, average reaction time = 1.44 sec. (standard deviation .58)
67% ratio, average reaction time = 1.60 sec. (standard deviation .67)
100% ratio, average reaction time = 1.55 sec. (standard deviation .67)

The reaction times for the most part follow the pattern expected, increasing steadily from 33% to 67% with a slight drop from the 67% ratio to 100% ratio. The difference in means from the 67% ratio and the 100% ratio were found to be insignificant in post-hoc analysis ($t=.235$, $p=.45$). Therefore, despite the slight insignificant reduction in reaction time from the 67% ratio to the 100% ratio, the results are as expected.

The results depicted in Figure 6 do indicate the expected significant effect of aircraft size ratio on errors. The number of errors were found to be significantly greater for the inside-out display (110 total errors) as compared to the outside-in display (81 total errors). Additional results from the chi-square test indicate no significant differences in sizes, as measured by the dependent variable errors, and no significant interaction between sizes and displays. The results indicated the total number of errors committed on the 33%, 50%, and 67% ratio were equal (46). A correlation was computed between the reaction time data and the error data to determine if they were negatively correlated as one might expect. (As reaction time increases, errors are reduced. As reaction time decreases, errors are increased.) The results of this analysis indicate that their is not a strong correlation (r=-.15) between reaction time and errors.

The results depicted graphically in Figure 7 with the roll component of the RMS error as the dependent variable do indicate a preference for the outside-in display. The strong result (P=.02) indicates the violation of the principle of the moving part (Roscoe 68) was a cause of confusion for the subjects. The subjects tended to fly the horizon in the inside-out display as opposed to the aircraft symbol. This would explain the superior performance on the outside-in display. The aircraft size ratio was not significant in this case. I feel this result, along with the lack of interaction effects, can be attributed to high individual differences which probably overwhelmed any subtle significant effects.

The results depicted graphically in Figure 8 do not indicate any significant effects. The reasoning behind the lack of a significant display effect is easily construed. Subjects on either display type could readily discern whether the aircraft symbol was above or below the artificial horizon symbol. The inputs on whether to climb or dive (to correct the pitch component of RMS error), were obvious. Despite not being significantly different, it is interesting to note that the inside-out display is always consistently worse than the outside-in display. Size was not a significant factor in Figure 8 or Figure 9. The lack of a significant size effect, along with the absence of any interaction effects, may be attributed to large subject variability, especially in the dynamic phase of the experiment.

Additional statistical tests were employed to determine if the ordering of phase sequence affected subject performance. The five dependent measures did not reveal any significant differences between the subjects who experience the static phase initially and those who experienced the dynamic phase first. A t-test was also conducted on the reaction time data to determine if subjects differed significantly in their responses to the 15° banks and the 45° banks. The mean reaction time for the 15° and 45° banks were respectively 1.27 seconds (s=.332) and 1.42 seconds (s=.38). The t-statistic calculated was 1.28 and was not significant at $\alpha=.05$ and 19 degrees of freedom. (It was initially felt that the larger arc created by the 45° bank may provide an unfair edge in ease of interpretation compared with the 15° bank. This was evidently not the case.)

In conclusion, I feel the static phase of the experiment was more conducive to determining any significant effects of aircraft size on the interpretability of aircraft attitude. This phase was realistic in that it tested a subjects reaction to a sudden awareness of a change in attitude. The lack of significant results from the measurement of errors was due in part to the minimal number of errors committed. I feel running this phase of the experiment over with a secondary task required of the subjects would more clearly indicate the effects of aircraft size on interpretability.

The dynamic phase was less realistic in a sense, due to the subjects constantly monitoring and correcting attitude. This certainly would not be the case in a "real" flying situation. I feel this phenomena of continually manipulating attitude detracted from any potential detection of a significant size effect. This phase allowed subjects to become accustomed to a certain aircraft symbol size in each trial, minimizing the influence of size. This phase did, however, in general, provide a good method of testing the two display types.

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APPENDIX

(Date)

SUBJECT: Consent of Volunteer

1. I hereby volunteer to participate as a subject in the investigation which has as its purpose the determination of the significance of wingspan on an aircraft attitude indicator. Two display styles will be used, namely the inside-out and the outside-in styles for this purpose.

2. I realize that the study will have no harmful physical or mental effects upon me, and I am aware of the disposition of the data to be collected.

3. I understand that my participation is voluntary, any questions I may have at any time will be answered, and that I may terminate my participation in the study at any time without prejudice to me at that time or in the future.

Signature of Subject

Signature of Experimenter

Study performed under the advisement of:

Jefferson M. Koonce, Ph.D.
Bruce G. Coury, Ph.D.

Department of Industrial Engineering and Operations Research

Dependent Variable: Reaction Time

Display: $F(1,19)=4.76$, $P<.05$

Sizes: $F(3,57)=6.17$, $P<.01$

Display x Sizes: $F(3,57)=2.42$ $P=.0896$ (approached significance)

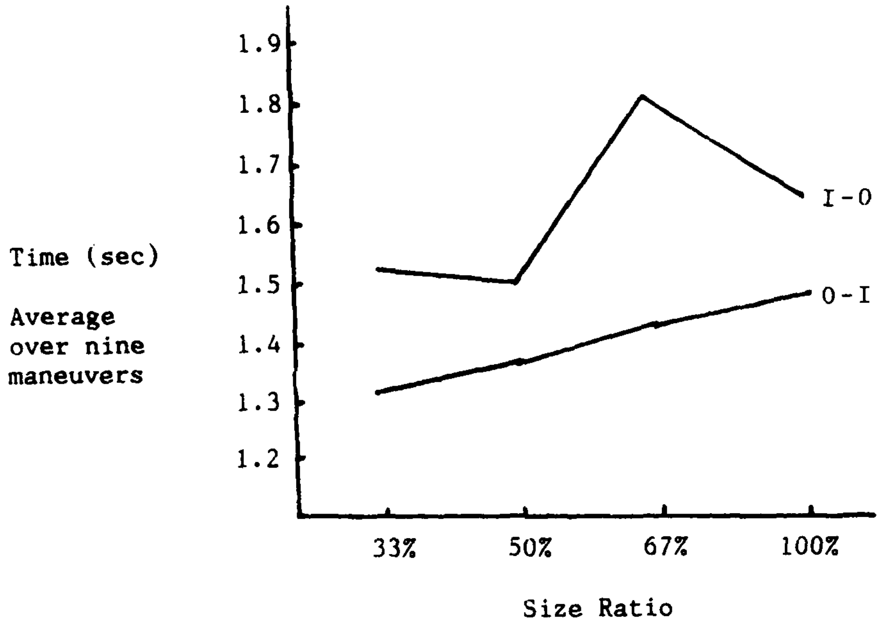

FIGURE 5: Graphical Results with Reaction Time
as the Dependent Variable

Dependent Variable: Errors

Display: $\chi^2_{\text{calculated}} = 4.40$

$\chi^2_{\nu=1,\alpha=.05} = 3.842$; Significant

Sizes: $\chi^2_{\text{calculated}} = .769$

$\chi^2_{\nu=3,\alpha=.05} = 7.815$; Not Significant

Dispaly x Sizes: $\chi^2_{\text{calculated}} = 2.561$

$\chi^2_{\nu=3,\alpha=.05} = 7.815$; Not Significant

$$\chi^2 = \sum \frac{(fo-fe)^2}{fe}$$

FIGURE 6: Results of Chi-Square Test on Error Frequency Data

Dependent Variable: RMS Error Due to Roll

Display: F(1,19),=6.36 P=.02

Sizes: F(3.57)=1.25 Not Significant (.29)

Display x Sizes: F(3,57)=.42 Not Significant (.68)

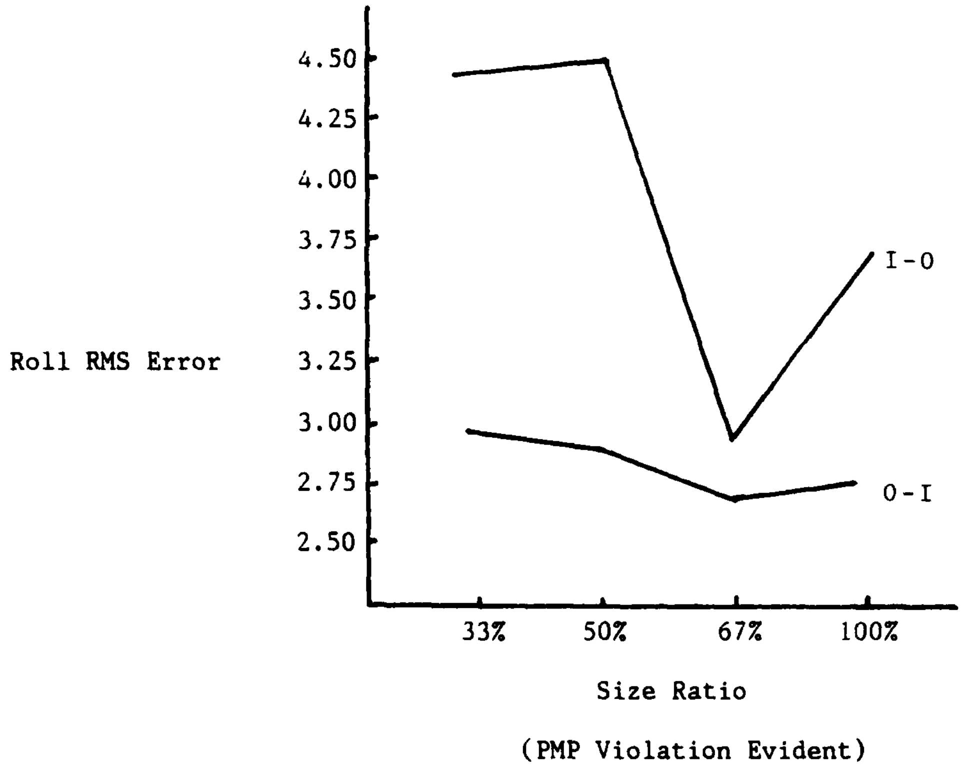

FIGURE 7: Graphical Results with Roll Component of RMS Error as Dependent Variable

Dependent Variable: RMS Error Due to Pitch

Display: $F(1,19)=1.44$ Not Significant (.24)

Sizes: $F(3,57)=2.47$ Approaching Significance (.09)

Display x Sizes: $F(3,57)=.41$ Not Significant (.69)

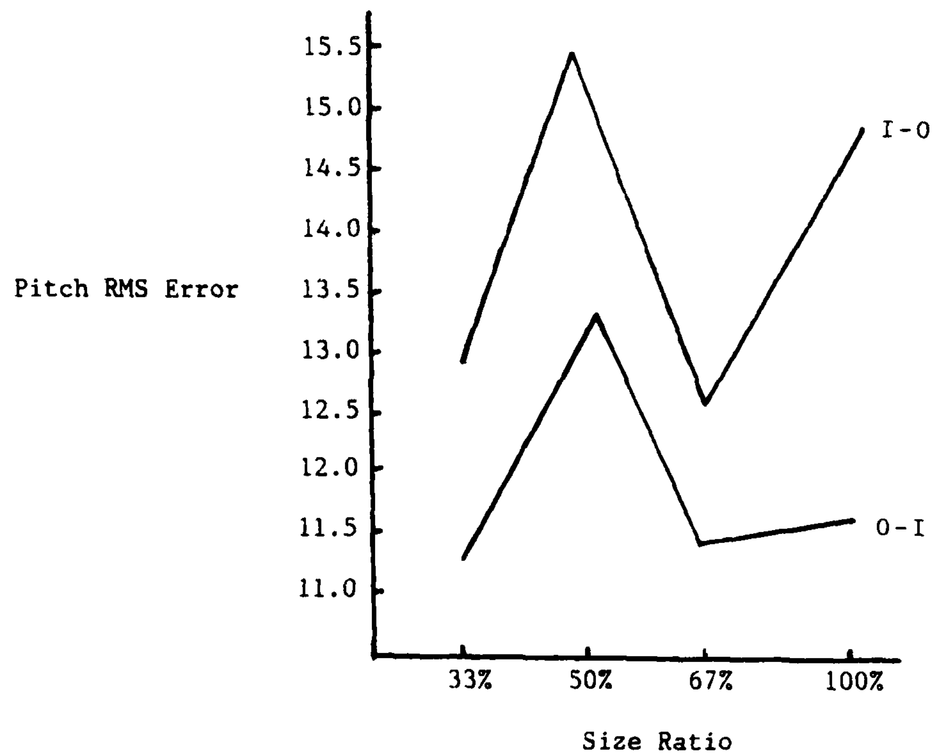

FIGURE 8: Graphical Results with Pitch Component of RMS Error as Dependent Variable

Dependent Variable: Normalized Total RMS Error

Display: F(1,19)=4.02 Approached Significance (.059)

Sizes: F(3,57)=1.40 Not Significant (.20)

Display x Sizes: F(3,57)=.51 Not Significant (.60)

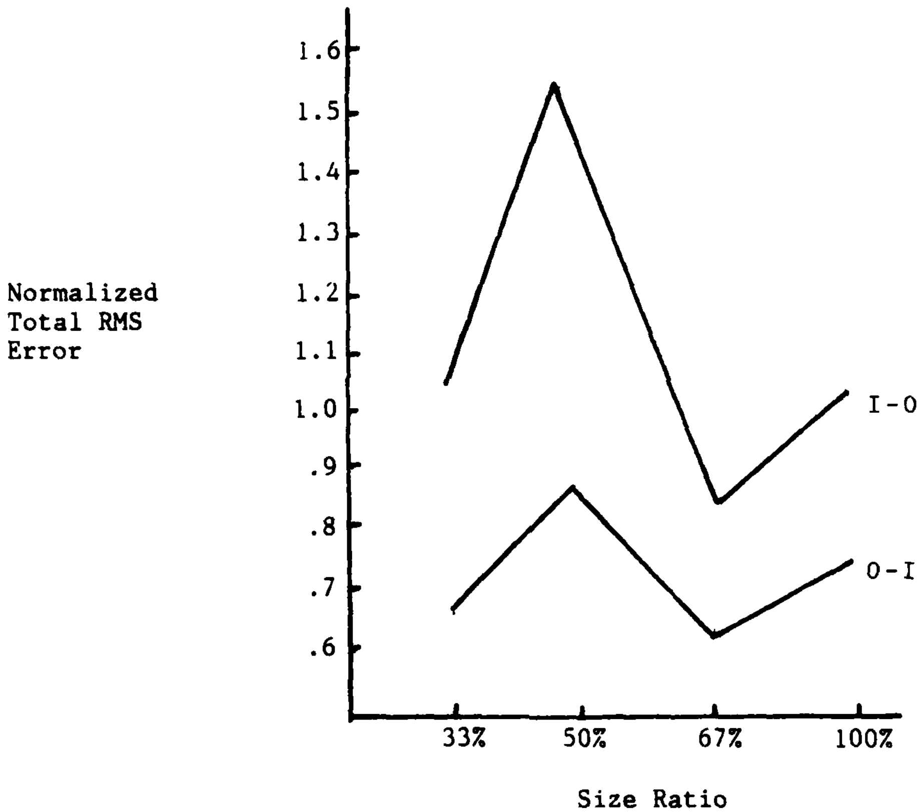

FIGURE 9: Graphical Results with Normalized Total RMS Error as the Dependent Variable

TABLE 3: ANOVA Table with Reaction Time Data

Source[1]	SS[2]	DF[3]	MS[4]	F[5]	TP[6]
Mean	360.210	1	360.210	397.57	0.000
Error	17.214	19	.906		
Display	1.515	1	1.510	4.76	.042
Error	6.052	19	.320		
Size	.959	3	.319	6.17	.002
Error	2.956	57	.051		
Display x Size	.375	3	.125	2.42	.089
Error	2.944	57	.052		

1 = source of variance
2 = sum of squares
3 = degrees of freedom
4 = mean sum of squares
5 = f-test value
6 = tail probability

TABLE 4: Chi-Square Test on Error Data

	S1 (33%)	S2 (50%)	S3 (67%)	S4 (100%)	
D1 (Outside-In)	18[1] (19.5[2])	23 (19.5)	16 (19.5)	24 (22.48)	81
D2 (Inside-Out)	28 (26.5)	23 (26.5)	30 (26.5)	29 (30.52)	110
	46	46	46	53	191

1 = observed value

2 = expected value

TABLE 5: ANOVA Table with Roll RMS Error Data

Source[1]	SS[2]	DF[3]	MS[4]	F[5]	TP[6]
Mean	1782.492	1	1782.492	173.23	0.000
Error	195.500	19	10.289		
Display	47.655	1	47.655	6.36	.021
Error	142.370	19	7.493		
Size	25.274	3	8.425	1.25	.298
Error	383.161	57	6.722		
Display x Size	9.213	3	3.071	.42	.682
Error	421.307	57	7.391		

1 = source of variance
2 = sum of squares
3 = degrees of freedom
4 = mean sum of squares
5 = f-test value
6 = tail probability

TABLE 6: ANOVA Table with Pitch RMS Error Data

Source[1]	SS[2]	DF[3]	MS[4]	F[5]	TP[6]
Mean	26384.403	1	26384.403	174.39	0.00
Error	2874.633	19	151.296		
Display	172.370	1	172.370	1.44	.25
Error	2274.610	19	119.716		
Size	168.931	3	56.310	2.47	.07
Error	1300.325	57	22.813		
Display x Size	31.123	3	10.374	.41	.69
Error	1440.862	57	25.278		

1 = source of variance
2 = sum of squares
3 = degrees of freedom
4 = mean sum of squares
5 = f-test value
6 = tail probability

TABLE 7: ANOVA Table with Normalized Total RMS Error Data

Source[1]	SS[2]	DF[3]	MS[4]	F[5]	TP[6]
Mean	137.215	1	137.215	70.90	0.0000
Error	36.769	19	1.935		
Display	6.819	1	6.819	4.02	.0593
Error	32.200	19	1.695		
Size	4.286	3	1.429	1.40	.2530
Error	58.255	57	1.011		
Display x Size	1.398	3	0.466	.51	.6000
Error	52.331	57	0.918		

1 = source of variance
2 = sum of squares
3 = degrees of freedom
4 = mean sum of squares
5 = f-test value
6 = tail probability

TABLE 8: Reaction Time Data Averaged Over the Nine Maneuvers (in Seconds)

	Outside-In (D1)				Inside-Out (D2)			
	S1 (33%)	S2 (50%)	S3 (67%)	S4 (100%)	S1 (33%)	S2 (50%)	S3 (67%)	S4 (100%)
Subject 1	1.08	2.07	1.16	1.31	1.04	0.98	1.36	1.11
2	1.78	2.16	1.93	2.29	1.64	1.67	2.20	1.82
3	1.00	1.07	1.33	1.49	1.12	1.09	1.47	1.38
4	1.44	1.42	1.44	1.38	1.18	1.27	1.46	1.49
5	1.18	1.22	1.18	1.53	2.11	1.93	3.53	1.93
6	0.93	1.27	1.44	0.96	1.09	1.58	1.58	1.20
7	1.49	1.49	1.60	1.44	2.31	2.67	2.51	2.11
8	1.07	1.56	1.31	1.56	1.16	1.16	1.04	1.24
9	1.32	0.79	0.84	0.96	1.49	1.36	1.71	1.13
10	0.84	0.82	1.14	0.88	1.27	1.13	1.16	0.96
11	1.04	1.02	1.00	1.11	1.18	1.11	1.44	1.49
12	1.20	1.18	1.27	1.38	1.16	1.07	1.11	1.02
13	1.00	1.33	1.24	1.31	2.29	1.44	1.98	1.33
14	2.11	2.11	2.40	2.60	1.98	1.47	1.76	2.91
15	1.53	1.62	1.56	1.67	2.07	2.51	2.58	2.71
16	1.40	1.33	1.64	1.71	1.31	1.31	1.53	1.38
17	1.42	1.49	1.47	1.89	1.68	1.36	1.96	1.62
18	1.82	1.76	1.58	1.62	1.33	1.64	1.84	1.89
19	1.13	1.13	1.31	1.20	1.31	1.69	1.67	1.67
20	1.53	1.73	1.64	1.51	1.43	1.50	1.69	1.76

TABLE 9: Total Errors Made Over the Nine Maneuvers

	Outside-In (D1)				Inside-Out (D2)			
	S1 (33%)	S2 (50%)	S3 (67%)	S4 (100%)	S1 (33%)	S2 (50%)	S3 (67%)	S4 (100%)
Subject 1	1	1	1	0	1	0	1	1
2	0	0	3	0	0	0	2	1
3	2	1	0	1	2	0	3	1
4	1	0	1	2	0	2	1	1
5	0	2	0	0	3	2	0	2
6	3	1	2	2	1	2	4	1
7	0	0	0	1	2	0	2	2
8	0	3	1	1	2	1	2	3
9	1	1	3	1	3	1	3	3
10	1	0	2	2	3	3	1	2
11	2	0	1	2	1	3	2	3
12	1	0	0	1	2	1	3	1
13	0	1	0	1	0	0	0	0
14	1	4	1	2	0	1	2	0
15	0	0	0	0	1	0	0	2
16	2	2	0	2	1	2	0	1
17	0	0	0	0	0	1	0	1
18	3	3	0	4	2	2	1	0
19	0	2	1	2	4	2	2	3
20	0	2	0	0	0	0	1	0
TOTALS	18	23	16	24	28	23	30	29

TABLE 10: Roll RMS Error Data

		Outside-In (D1)				Inside-Out (D2)			
		S1 (33%)	S2 (50%)	S3 (67%)	S4 (100%)	S1 (33%)	S2 (50%)	S3 (67%)	S4 (100%)
Subject	1	3.06	2.69	2.34	2.51	2.52	2.27	2.57	4.62
	2	4.54	5.84	2.91	5.04	3.92	4.81	4.57	4.08
	3	7.49	3.80	4.84	5.02	3.21	3.94	4.43	4.22
	4	3.19	4.19	2.44	3.37	3.97	3.11	2.61	2.50
	5	2.33	1.98	2.02	1.93	4.18	2.90	2.39	2.16
	6	1.54	1.85	1.34	1.37	1.80	1.90	1.76	2.62
	7	3.16	2.24	2.17	2.21	4.14	25.41	2.83	4.34
	8	2.56	3.11	3.54	3.48	3.06	2.56	2.05	4.76
	9	2.09	2.05	3.18	1.88	2.84	2.82	2.41	11.75
	10	2.28	1.96	1.70	1.54	2.03	1.58	1.81	1.86
	11	2.77	3.68	3.00	2.50	2.27	2.37	2.80	2.87
	12	3.56	3.03	3.07	2.67	3.42	3.33	3.53	2.89
	13	3.20	2.37	3.65	2.77	5.05	3.57	4.22	4.43
	14	2.33	2.96	3.11	2.63	24.39	1.97	4.33	1.75
	15	1.78	2.26	2.37	1.34	4.00	2.57	2.40	2.92
	16	2.18	2.29	1.41	2.63	3.52	3.65	5.30	3.00
	17	2.15	2.42	1.40	1.88	2.29	1.83	1.54	2.45
	18	2.60	2.03	2.46	2.33	2.67	3.82	2.16	3.27
	19	3.34	5.55	2.38	2.90	6.56	8.54	3.48	3.87
	20	3.78	2.81	2.81	2.68	3.31	3.67	3.60	3.76

TABLE 11: Pitch RMS Error Data

	Outside-In (D1)				Inside-Out (D2)			
	S1 (33%)	S2 (50%)	S3 (67%)	S4 (100%)	S1 (33%)	S2 (50%)	S3 (67%)	S4 (100%)
Subject 1	10.18	11.86	16.90	18.98	8.45	10.89	8.80	8.49
2	18.76	27.49	14.88	17.37	8.35	10.09	10.50	18.71
3	15.13	11.85	15.59	10.80	13.99	31.68	13.95	25.04
4	11.83	11.81	10.27	11.29	10.46	9.07	13.94	11.71
5	6.09	12.21	7.46	10.16	18.75	14.05	15.84	14.29
6	5.50	7.30	5.52	8.00	5.87	5.87	4.83	9.84
7	7.10	7.01	7.77	6.39	28.18	57.51	33.30	29.29
8	16.45	19.94	14.91	14.30	12.59	13.95	16.89	35.74
9	9.22	11.66	18.43	5.85	13.99	12.73	15.48	17.08
10	11.67	8.64	8.24	8.40	8.39	8.54	9.16	8.20
11	8.76	14.06	7.07	8.96	5.28	6.24	6.46	8.68
12	15.82	17.66	10.50	17.04	13.09	8.03	12.98	10.87
13	16.60	10.44	16.06	17.32	26.57	17.16	22.21	10.23
14	12.05	16.38	13.23	7.66	12.22	10.56	8.45	12.62
15	9.06	18.14	9.00	9.60	7.82	8.86	9.90	16.89
16	8.25	9.99	6.57	7.22	8.37	7.23	9.77	6.29
17	5.93	6.02	7.49	7.09	7.44	6.39	6.12	7.48
18	13.36	6.44	10.35	11.68	13.43	22.71	9.78	23.81
19	9.32	30.71	13.52	18.59	25.09	37.49	10.61	11.72
20	14.45	8.49	10.97	9.22	9.98	10.18	8.11	8.76

NOTE: The roll and pitch components are combined algebraically to form the total RMS error data.

END

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DTIC